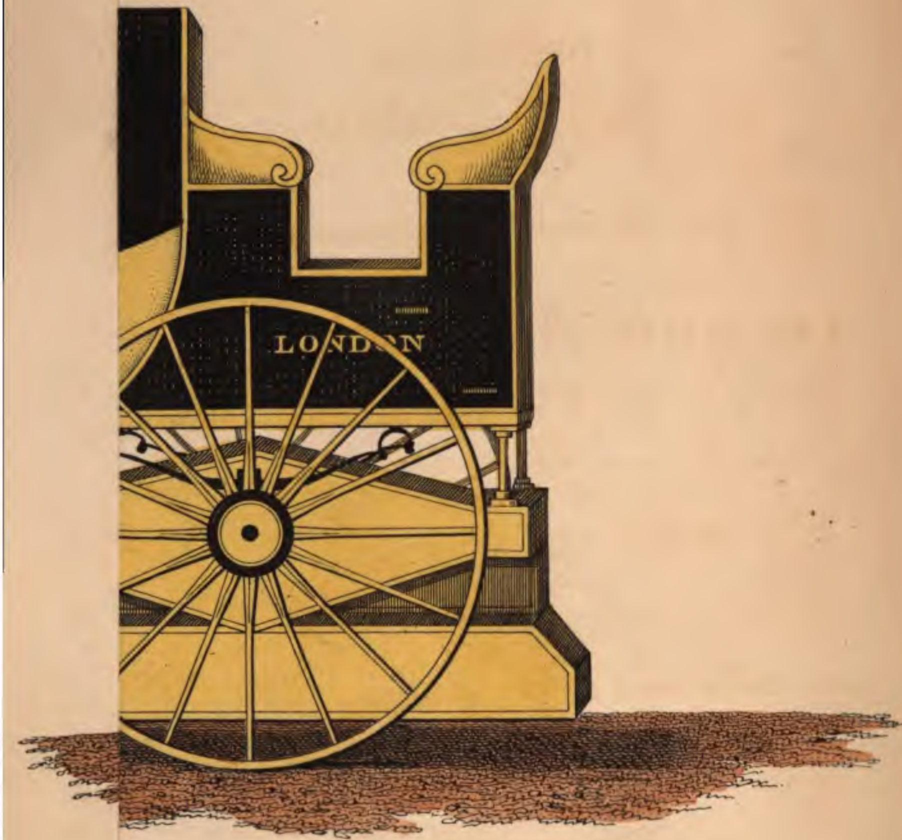
MANN'S
LOCOMOTIVE
AIR
CARRIAGE.



1.


2


REFERENCES
(continued.)

3. Fifteen Reservoirs containing 75 Cubic Feet.

4. A Reservoir taken out of the Case.

IR CARRIAGE.

a density of 32 atmospheres is

atmospheres 34 Miles.

A DESCRIPTION

OF A

NEW METHOD OF PROPELLING

LOCOMOTIVE MACHINES,

AND OF

COMMUNICATING POWER AND MOTION

TO

ALL OTHER KINDS OF MACHINERY.

BY THE PATENTEE,

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INTRODUCTION.

Before entering on this subject it may be premised, that the matters herein contained are intended to be made intelligible to the unscientific, as well as the scientific, reader, and therefore the necessary illustrations will be taken from the most familiar objects, and the calculations stated in a way, that every person, conversant with the elements of common arithmetic, will readily understand.

By the method of communicating power and motion, as hereafter described, it will be found:

That if atmospheric air were compressed to the same density as portable gas, a quantity might be carried by a locomotive machine sufficient to propel it twenty miles, and the cost not exceed one penny per mile.

That a locomotive machine, when drawing twenty tons on a rail-way, could carry sufficient to propel it upwards of a hundred miles.

That the cost of power to convey goods on the rail road from Liverpool to Manchester, being 31 miles, would not exceed one halfpenny per ton.

That cheap mechanical power could be obtained from the waste coal produced at the coal mines, and supplied to the artizans in the manufacturing towns, in the same way that the inhabitants of Surrey are now supplied with light, from gas manufactured in Kent.*

And that artillery, and all such machines, as are now called fire-arms, might be supplied with power which would give a projectile force equal to gunpowder, at less than the one hundredth part of the present cost of that article.

General observations on mechanical power, and on concentrating and packing it up for various purposes.

I. The cheap mechanical power derived from wind, water, and steam, has very generally superseded animal labour, in those cases where it is practicable to convey the work required to be performed to the power that is to perform it. But as the machines used to generate and produce such power are, of necessity, stationary, — the grist must be carried

* The gas is manufactured near Greenwich.

to the mill, the mill cannot be carried to the grist; such being the case, whenever it becomes necessary for the operative power to travel along with any kind of machines in performing the work, as in all cases of land conveyance and field labour in agriculture, then those mechanical generators of cheap power have hitherto been totally useless, and recourse, of necessity, had to the expensive labour of animals.

The object contemplated in the present patent, is to concentrate, pack up and make portable such mechanical power, so that it may afterwards be used at any time and place, however distant from the mills, engines and machinery by which it is generated.

The idea of packing up and making portable any thing so evanescent as power may appear somewhat fanciful, until we call to mind that it has been familiar to us from our infancy.

II. The watch-maker furnishes a machine so ingeniously constructed, that its owner can, in a few seconds, pack into a small piece of elastic metal, called the spring, as much power as will propel and keep the machinery in motion upwards of thirty hours.

III. The air-gun shews another, (and for many purposes a better method of packing up power) an elastic fluid is then used instead of an elastic metal,

that is, atmospheric air instead of tempered steel; by this means a quantity of power, produced by manual labour, is packed into a small reservoir, for the purpose of being afterwards used as a projectile force in lieu of gunpowder.

In a similar way portable gas is packed up, and in a similar way it is proposed to pack up, and make portable, the cheap mechanical power before mentioned, for the purpose of its being afterwards used in propelling locomotive machines, and for various other purposes.

IV. The Portable Gas Company may be said to pack into their reservoirs two things, namely, *steam power* and carburetted hydrogen *gas*, the *power* being used to make the *gas* portable; when that object is obtained, the *gas* is used, and the *power* thrown away.

V. For propelling locomotive and other machines, it is intended to pack into similar reservoirs two things also, namely, *steam*, *wind*, or *water power*, and atmospheric *air*; the *air* being used to make the *power* portable: when that object is obtained the *power* is to be used, and the *air* thrown away.

In this way atmospheric air, like tempered steel, may be made a useful depository of mechanical power; and the fluid has this advantage over the metal, its elastic property is boundless: at least, as far as human knowledge extends, its capability of

compression and expansion is without limit. It may, therefore, be charged with mechanical power as long as the reservoirs can be made sufficiently strong to contain it. And with the improved condensing pumps (described in the appendix *A*), it can be compressed not only to thirty or forty atmospheres, which will render it sufficiently portable for locomotive machines; but to a thousand atmospheres, if required.

On the application of portable power to propelling locomotive machines on turnpike roads.

I. This method of concentrating, packing up, and carrying the power ready prepared for use, would have several advantages over that of generating it on the road, as is done by locomotive steam engines. It would be cleaner, cheaper, and lighter. Cleaner, as it would get rid of the boilers, furnaces, heat, and smoke.—Cheaper, because, it is well known, that a large fixed steam engine, in a warm engine-house, will generate as much power from one bushel of coals, as a locomotive engine, when passing rapidly through a cold temperature, will generate from three.—Lighter, because the weight of the reservoirs of air would not be more than one half of the weight of the boiler, furnace, coals, water, &c. of the locomotive steam carriage.

II. It will not be necessary to give the mechanical details of the application of the power when so concentrated and packed up, because the compressed

air is made to act by pistons and cylinders, in precisely the same way as high pressure steam, excepting that as air at the density of portable gas has seven times the pressure of steam as generally used, it will require to be wire drawn, (as it is called,) down to the working pressure; which is done by the conductor of the machine partially opening a cock or valve, and admitting just so much air into the working cylinders as will give the power and speed required; and when the machine has to pass over bad or new made roads, or to ascend hills, then the conductor by opening the cock a little more, will admit a greater quantity of the condensed air into the working cylinders, and thereby give the power of ten or twenty horses if required; and that he may never be without the means of giving this additional power, two or three reservoirs should be kept fully charged, from which he may, by another cock or valve, supply such extra demand, should it occur when the density of the fluid in the main reservoirs is reduced too low to furnish it.

The supply of condensed air to the working cylinders must be cut off at the fourth, third, or other part of the stroke of the piston: so that the air may be worked down to atmospheric pressure, or nearly so, before it is discharged from the cylinders.

The place for cutting off such supply will depend on the size of the working apparatus; for, on that will depend the density down to which the fluid will be wire drawn.

The phrase wire drawn, when applied to elastic fluids, will be understood, when it is considered that all the gas in London is wire drawn; that is, a cock in the gas tube is turned just so much as to admit a proper quantity of the fluid to supply the requisite degree of light, whatever may be the pressure; and the variations of pressure in portable gas is very great; sometimes exceeding four hundred pounds on the inch, at other times reduced below ten; notwithstanding which, the supply is regulated in this simple way.

III. The quantity of mechanical power required to propel a locomotive machine, carrying the same number of passengers and quantity of luggage as a four-horse coach, will be found in the following way:

The average power of draft of a horse, when moving in a mill track, at a speed of little more than two miles per hour, is estimated as being equal to the power required to lift 44000 pounds weight one foot high per minute: and from this data the horsepower of steam engines is usually calculated. When the animals are forced to increased degrees of speed, their power of draft becomes proportionably diminished: so that when travelling at a speed of ten miles per hour, the power expended in carrying forward their own bodies, reduces their power of draft to one half; it being then equal only to the power required to lift 22000 pounds weight one foot high per minute.

The power required to propel a machine equal to a four-horse coach ten miles, within one hour, will be found by calculating the power expended by four horses in performing the same labour; and this may be done by multiplying 22000, the lift of each horse per minute, by 4, the number of horses, and that product by 60, the minutes employed, as $22000 \times 4 \times 60 = 5280000$ pounds weight, lifted one foot high.

IV. The quantity of air, requisite to give a force equal to 5280000 pounds lifted one foot high, may be ascertained by reference to the table in the appendix *B*, in which the elastic force of a cubic inch is given in pounds weight lifted one foot high, under sixteen different degrees of density, calculated to the hundredth part of a pound weight. In the fourth column of that table it will be found that a cubic inch of air, when under a pressure of 32 atmospheres, has an expansive force equal to 111,25 pounds lifted one foot high, and the number of cubic inches required will be ascertained by dividing 5280000 by 111,25, as under:

Cubic inches.

$$\frac{5280000}{111{,}25} = 47600, \text{ or } 27 \text{ feet, } 804 \text{ inches.}$$

The same table shews that a cubic inch of air under a pressure of 48 atmospheres, is equal to a lift of 191,25 pounds one foot high, and an inch at 64 atmospheres is equal to a lift of 281,25 pounds one foot high; the quantity required at each of those densities, to propel a locomotive machine

equal to a four-horse coach, ten miles, will be as follows :

	Cubic Inches.		Feet.	Inches.
At 48, $\frac{5280000}{191,25}$	=27607,	or	15,	1687.
At 64, $\frac{5280000}{281,25}$	=18776,	or	10,	1496.

But in thus packing up and transfering such power, there will be some loss by friction, and about one-tenth of the power will remain in the reservoirs unused; to allow for that, and for the additional weight of the machinery, &c. the subsequent calculations are made on the assumption that double the above estimated quantity of power will be required for ten, and consequently four times the quantity for twenty miles. The quantity proposed to be carried by such machine, at each of those densities, will be therefore as under:

		Feet.	Inches.	Feet.	Inches.
At 32	atmostpheres,	27,	804×4=	109,	1488.
At 48	ditto	15,	1687×4=	63,	1564.
At 64	ditto	10,	1496×4=	33,	800.

Suppose the reservoirs were made to contain $3\frac{1}{2}$ cubic feet each, then it would require 31 reservoirs to contain the above quantity when at a pressure of 32 atmospheres, eighteen when under a pressure of 48, and ten when at a pressure of 64 atmospheres.

V. The weights of the reservoirs may be stated as follow :—The reservoirs made to contain $3\frac{1}{2}$ cubic

feet of gas, under a pressure of 30 atmospheres, weigh about 60 pounds; those for 32 atmospheres of air, may, therefore, air included, be taken at 70 pounds each, and the others being taken at a proportionate strength, the weight will be as under:

At 32	atmospheres	$70 \times 31 = 2170$	pounds,
At 48	ditto	$105 \times 18 = 1890$	ditto,
At 64	ditto	$140 \times 10 = 1400$	ditto.

These weights are considerable, but the reservoirs used by the Portable Gas Company appear to be made heavier than necessary to sustain a pressure of 30 atmospheres; for, according to the estimated tenacity of the best malleable iron, they are sufficiently strong to resist a pressure of 141 atmospheres, (see appendix *C)*; and therefore they might very safely be charged to 48 atmospheres, which is little more than one third of their estimated capability; the tenacity of the best malleable steel is nearly double that of iron; so that if the reservoirs were made of that article, they might, at all events, be reduced one half in weight.

It will be seen by comparing air at a density of 64 with that at 32 atmospheres, nearly two thirds are saved in bulk by using it at the higher density; but only about one third in weight. The cost of the power will be precisely the same, whatever may be the density at which the fluid is used.

The pistons and cylinders may be considerably

smaller for air at those densities than could be used for high pressure steam; but there does not appear any material advantage to be derived from making them much smaller.

VI. The expense of power thus supplied comes next under consideration; and when obtained from wind or water, it would be somewhat difficult to estimate it with any degree of accuracy; but the expense of steam depending on the price of fuel at the places where it is generated, that can be ascertained without any difficulty. In London, the cost will be as follows: the horse-power of a steam engine, as before mentioned, is that quantity of power which is equal to 44000 pounds lifted one foot high per minute: a twenty-horse-power engine, will therefore, be equal to 880000 pounds lifted one foot high per minute, as $44000 \times 20 = 880000$. The quantity of power expended in drawing a four-horse coach 10 miles is estimated as being equal to the power required to lift 5280000 pounds one foot high; and, for the reasons before mentioned, it is proposed to carry four times that quantity of power to propel a machine twenty miles; the quantity of power required will therefore be $5280000 \times 4 = 21120000$ pounds lifted one foot high; this amount of power being divided by 880000, the lift per minute of a steam engine of twenty-horse power, will shew that such engine would be 24 minutes in producing that quantity of power, as $\frac{21120000}{880000} = 24$ minutes. A twenty-horse power steam engine cannot be worked in London for less

than about 40*s*. per day, which is 1*s*. 4*d*. for the 24 minutes; so that the power requisite to propel a locomotive machine, equal to a four-horse coach, 20 miles would cost something less than a penny per mile; in the coal districts the cost would not exceed a halfpenny per mile.*

Observations on various kinds of power.

I. It may be asked, how is it possible there can be so much difference between the cost of steam power and animal labour, when a steam engine costs two shillings per day for each horse power, and a horse can be maintained a day for three shillings?

The answer to this question will shew the immense waste of animal labour when used in drawing carriages at great speeds. The proprietors of fast coaches say they require a horse per mile, or rather what is called a horse per double mile; that is, it requires about 186 horses to keep a four-horse coach running daily *to* and *from* London to Man-

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* In the neighbourhood of the coal mines mechanical power may be literally said to cost "*almost nothing*;" for reckoning the coals at 10*s*. per ton, a large steam engine will generate power equal to a lift of one million of pounds one foot high for a farthing; this quantity of power, by horse labour, under the most favorable circumstances, would cost two pence: so that ploughs, and all other agricultural machinery, might, in those districts, be profitably worked in this way.

chester, the distance being 186 miles; each horse, therefore, on an average, goes only eight miles per day; which, at ten miles per hour, is performed in 48 minutes; so that when a horse is forced to that speed, not only his power of draft is reduced one half; that is, from a 44000 to that of 22000 pounds weight lifted one foot high per minute; but his time of labour is also reduced to only 48 minutes in each 24 hours: this 48 minutes of half labour, therefore, cost three shillings; while a steam engine works twelve hours, lifting in each minute 44,000 pounds one foot high, for each horse power, at an expence of only two shillings the horse power: the work performed by the steam engine for two shillings will consequently be $44000 \times 60 \times 12 = 31680000$: that by the horse for three shillings $22000 \times 48 = 1056000$; then by dividing the quantity of work performed by the steam engine by that performed by the horse, the difference will be found as thirty to one, as $\frac{31680000}{1056000} = 30$, and as the cost is also as three to two, the real difference of expense is as 45 to 1.

II. This waste of animal power will appear more evident if animal labour expended in one way is contrasted with animal labour expended in another; a horse in a mill, going at a moderate speed, will lift 44000 pounds weight one foot high per minute, and continue to do so for six hours out of every twenty-four. The difference between the labour performed by the mill horse, and the coach horse, will be as follows:

	Pounds weight lifted one foot high per Minute.		Minutes employed.		Pounds weight lifted one foot high by each horse per Day.
Mill-horse	44000	×	360	=	15840000
Coach-horse	22000	×	48	=	1056000

By dividing the larger sum by the smaller, it appears that *one* mill horse performs as much work as *fifteen* coach horses when travelling ten miles per hour, as $\frac{15840000}{106000} = 15$. Thus even horse labour might be advantageously employed in this way, when other power could not be conveniently obtained, and on roads where the trafic was insufficient to employ a small steam engine.

III. The power of six men is estimated as equal to that of one horse; but suppose it required ten persons on a tread mill, to produce a quantity of power equal to one horse going in a mill track, then a tread mill working *twelve* hours, with always ten persons on it, would produce as much power per day as *two* horses in a mill working six hours each, or *thirty* horses in the fast coaches working 48 minutes each. Thus the labor of the persons at the various tread mills, which is now thrown away in grinding the wind, as it is called, might be profitably employed. Apropos of tread mills. The march of intellect seems to be getting on rapidly in some quarters. A worthy Alderman has recently discovered that if the tread mills were employed on productive labor, by which the prisoners would earn their own food and raiment, the effect would be mischievous to the rest of the community; so that it appears the hard-working part of his Majesty's subjects who are out of prison,

are benefitted by being obliged to find provision and clothing for those that are in. They have a saying in China, that if a man eats his dinner before he earns it, he causes some other person in the empire to go without. In England, on the contrary it would appear, that if a man earns his dinner before he eats it, he produces a similar evil. It may be somewhat difficult to reconcile such conflicting statements, but as there is no rule without an exception, if the persons confined in Clerkenwell and other prisons, were made to earn their dinners by compressing air instead of grinding it, and thereby supplying power for propelling his Majesty's mails throughout the kingdom, the evils so much dreaded, would be avoided, as then horses only, and not men, would be deprived of their dinners.

Methods of supplying machines with power on long lines of road.

I. For supplying with power such machines as travel great distances, it is proposed to have steam engines, condensing pumps and reservoirs, stationed at every fifteen or twenty miles; from which the machines could be recharged, and not detained two minutes; for air under the proposed pressures, will travel from four to five thousand feet per second; but suppose it passed through a flexible Indian-rubber pipe, at two thousand feet per second, then a pipe of half an inch area, would convey one hundred cubic feet from the stationary reservoirs to those

attached to the locomotive machines, in less than thirty seconds. The preceding estimates are made on the assumption that the machines will be propelled ten miles per hour; but as far as this method of supplying power is concerned, twenty or thirty miles may be travelled in that period of time, and that without any danger of upsetting; for the centre of gravity will be brought so low by the reservoirs being placed under the machines, that there is scarcely any possibility of overturning whatever the speed. It is, however, probable, that even by this method, general travelling will not much exceed twelve miles per hour; but there appears no reason why the mail bags should not be carried fifteen miles per hour, or more, by small compact machines just sufficient to contain the bags, conductor and guard: and as the propelling power is so cheap, they need not, and ought not, to carry passengers and luggage as a saveall.

II. If the whole or a greater part of the traffic on a public road were carried on by locomotive machines propelled by air, a range of iron pipe, of seven inches area, would supply the whole line; and the machines could be charged directly from the pipes, in the same manner that water-carts are now supplied with water in London. Suppose, for instance, the line of road from Manchester to London (186 miles) were supplied with propelling power in this way, the expense would be as follows: iron pipe, of seven inches, costs one shilling and two pence per foot, or £57,288 for 186 miles. To

prevent delays by repairs, or other causes, two lines of pipe might be provided, the costs of which would be £114,576 : if this outlay of capital appears great, it should be borne in mind that, by this arrangement, not only the whole outlay for steam engines, condensing pumps, and reservoirs, at the several intermediate stations would be saved; but the expense of generating the power would also be materially reduced, as one or more large steam engines, in the neighbourhood of the coal mines nearest the line of road, would generate all the power required from coals, which would there cost only from 4*s.* 6*d.* to 5*s.* per ton; while in London the same quantity of fuel costs from 30*s.* to 40*s.*

The idea of conveying mechanical power, by means of an elastic fluid, from Manchester to London, a distance of 186 miles, will not appear extravagant, when it is considered that, in London, light is transmitted, by means of an elastic fluid, through a line of pipes upwards of a thousand miles in extent.

III. If on commencing a line of road it should be thought desireable to save the outlay for steam engines, condensing pumps, &c. at some or all of the intermediate stations, it might be done in this way: take, for instance, the line from London to Brighton, the steam engine at Brighton might generate the power for the nearest intermediate station, and send it 18 miles on the road, the steam engine at London doing the same. The expense of conveying the

power in this way would be but trifling, as the vehicles to carry it would also be locomotive.

An estimate of the firt cost and outlay of capital for eight locomotive machines, to run daily between London and Manchester; with the daily expenditure and probable receipts.

As this estimate is for only eight coaches, it is founded on the first plan of supplying power—that of having steam engines and condensing pumps, &c. at given distances. Each machine to be constructed for carrying six inside, and twelve outside passengers, and the same parcels and other luggage as a four horse coach: ten stations for providing power, at an average distance of $18\frac{1}{2}$ miles from each other: the speed from ten to twelve miles per hour.

I.—OUTLAY OF CAPITAL.

	£.	s.	d.
For ten steam engines of six horse power, estimated at £50 per horse power, say 10 at £300 each	3,000	0	0
Ten sets of condensing pumps and reservoirs at £500 per set	5,000	0	0
Eight locomotive machines at £500 each..	4,000	0	0
	£12,000	0	0

This outlay appears considerable, but it is much less than by the present method; the horses alone for eight coaches, at £20 each, would cost £14,880.

II.—DAILY EXPENSE.

	£.	s.	d.
Interest on the outlay of £12,000 at 5 per Cent. per Annum, at per Day	1	13	0
Wear and tear of steam engines and machinery, pumps and reservoirs, say on £8,000, at 5 per Cent.	1	2	0
Wear and tear of locomotive machines, say on £4000, at 20 per Cent.	2	4	0
Rent of eight engine-houses, at the country stations, at £10 per year each, say per day	0	4	6
Rent of warehouses and engine-houses in London and Manchester, say £100 per year, per day	0	6	0
Smiths' wages repairing machines in London and Manchester	0	8	0
Twenty-four conductors of machines at 4*s.*	4	16	0
Sixteen guards for ditto, at 3*s.*	2	8	0
Coals and attendance on each steam engine, at 15*s.* per day, say	7	10	0
Turnpikes per day	5	0	0
Mile duty 186 × 8 = 1488 at 3*d.*	18	12	0
Daily expense of eight machines	£44	3	6

The mile duty, which forms so large a portion of the daily expenditure, is added, because although not chargeable under the present acts, there is no doubt the Chancellor of the Exchequer would be on the alert; but really he should be merciful, and charge only three halfpence per mile, for unquestionably the traffic would be more than doubled, so that even then he would be money in pocket.

III.—DAILY INCOME.

The present coach fares are £3. 10*s.* for inside, and £1. 15*s.* for outside passengers; the fares proposed are £1. 1*s.* for the inside, and 10*s.* 6*d.* out;

and assuming they would average half the number for which they were adapted,

	£.	s.	d.
Say three inside passengers at one guinea each	3	3	0
Six outsides at 10s. 6d.	3	3	0
Large and small parcels	2	0	0
Daily receipts of each machine	£ 8	6	0

	£	s.	d.	£	s.	d.
Eight machines	8	6	0×8=	66	8	0
Daily expense				44	3	6
Daily profit				£22	4	6

The machines on which the above estimate is founded, are assimulated to the coaches in present use; but as every kind of vehicle could be propelled in this way, no doubt they would be constructed in various ways, as might suit public convenience, and also that the power would ultimately be provided on the road, by persons totally distinct from the proprietors of coaches, caravans, and other carriages.

On the application of power to propelling locomotive machines on rail-roads.

I. For railways this method has some advantages over locomotive steam engines, besides those enumerated for turnpike roads. One large fixed steam engine would generate power sufficient for fifty locomotive machines if required, and thereby save the expense of an engineer to each machine, and the

expense for fuel would also be considerably less; for, as before stated, one large steam engine, in a warm engine-house, will generate as much power from one bushel of coals, as a locomotive steam engine, travelling through a cold temperature, will generate from three.

II. The draft on a railway has been so variously stated, and the railways themselves have been constructed with such different degrees of perfection, or rather imperfection, that it is impossible to arrive at any unexceptionable data on which to found a general estimate; but, from some experiments recently made on the Liverpool railway, it has been ascertained that a quantity of power, equal to a lift of two pounds and a half, will propel a ton weight. The following estimate proceeds on the supposition that three times that quantity of power may be requisite; that is, a quantity of power equal to a continuing lift of seven pounds and a half for a ton weight, and by multiplying 5280, the number of feet in a mile, by 7,5, will give the lift in pounds weight required to propel a ton weight that distance: as $5280 \times 7{,}5 = 39600$ pounds weight lifted one foot high: by proceeding with this estimate, it will be found, that if locomotive machines on railways were propelled by steam power obtained in this way from fixed steam engines, the expense would not be half that of the locomotive steam engines.

III. Locomotive machines on railways carry neither goods nor passengers, but are solely employed in

drawing machines that do; they could therefore carry three hundred cubic feet of air; which, at a density of 32 atmospheres, would be sufficient to propel twenty tons upwards of seventy miles; and at a density of sixty-four atmospheres, upwards of one hundred and eighty miles (see Appendix *D*). This is not mentioned under any idea that it would ever be necessary to travel any thing like that distance, without stopping for a fresh supply of power, but to shew the large quantity of power which might always be had at command, when supplied in this way.

IV. To render the utility of this method more apparent, suppose the Liverpool and Manchester railway completed, and a steam engine, of one hundred and sixty horse power, placed near the centre between those two towns, or two of eighty horse power each, one being placed at the Manchester and the other at the Liverpool end thereof; then it will appear, by the following calculations, that, in either case, there would be power sufficient to propel upwards of four thousand tons weight daily between those two places, the distance being thirty-one miles, thus: $44000 \times 160 = 7040000$ pounds weight lifted one foot high per minute, by an engine of 160 horse power; then $7040000 \times 60 \times 12 = 5068800000$, its lift per day of twelve hours. The power requisite to propel a ton weight one mile (see preceding estimate, p. 19) is equal to 39,600 pounds weight lifted one foot high; therefore to convey a ton weight from Liverpool to Manchester will require $39600 \times 31 = 1227600$ lifted one foot high;

then by dividing the amount of the lift per day of the 160 horse power engine by 1227600, will give the number of tons weight that could be so conveyed per day, $\frac{5068800000}{1286600}=4129{,}04$ tons.

V. The daily expense for coals and attendance for one 160 or two 80 horse power engines will not, in that neighbourhood, exceed £5. Suppose then one third part of the before mentioned 4129 tons was constituted of machines and vehicles containing the goods, then the weight of the merchandize would be 2752 tons; this, at a halfpenny per ton, would amount to £5. 14*s*. 8*d*.

Suppose again, each machine were made to draw twenty ton weight of goods, and to make two trips per day, then it would require 68 machines to convey the 2752 tons of goods; and if locomotive steam engines were used, then 68 engineers also; but by the method proposed, the wages of 66 engineers would be saved; which would alone be equal to the whole cost of working the fixed steam engines. On all railways where there are fixed steam engines to draw the machines up inclined planes, a further saving might be made; for those engines, by being made sufficiently large, would supply all the power requisite to propel the machines along the levels.

VI. This method possesses another advantage not attainable by locomotive steam machines; the power may be used in such small quantities as to propel

two hundred weight as well as twenty tons; so that a merchant might travel on the rail road from Liverpool to Manchester and back, in a machine the size of a gig, with power that cost less than a penny.

Application of this method to propelling Post-office Packets.

I. For post-office packets, and other passage vessels, making short voyages, this method would have some material advantages over steam engines. It would get rid of the heat and smoke, and all danger of fire from the furnace; and also all possibility of sinking; for the reservoirs, placed in the hold, would keep the vessel afloat by their buoyancy, were she even filled with water. Each reservoir made to contain five cubic feet of air, will weigh about 100 pounds: and as they would severally occupy the space of five cubic feet of water, which weighs 312 pounds, a clear buoyant power of 212 pounds would be obtained from each reservoir. This is of some importance, when we consider the great number of persons that are continually passing between England and France, and England and Ireland.

II. When steam power is used to charge the reservoirs for this purpose, the saving might not be much; for although a fixed steam engine will generate a considerably greater quantity of power from a given quantity of fuel than those in steam vessels, yet that advantage would probably be lost in the

transfer. But those vessels which navigate, or depart from and return to navigable rivers, might obtain power at a very moderate expense, by having one or more barges (with two or three pair of paddle wheels in each) moored in the current of the river; then the influx and reflux of the tide, or the force of the descending stream, (if above the influence of the tide) would work the paddle wheels and condensing pumps, and compress the air to any density that might be required.

Ferry boats, which cross the mouths of rivers and arms of the sea, could thus be supplied with power to propel them; for, by a very little mechanical contrivance, the motion of their own paddle wheels might be reversed, and so made to recharge the reservoirs during the night, or at intervals in the day time, when they were not otherwise employed.

On working Cranes in Docks, &c.

About two years since Mr. Hague, the engineer, proposed to the directors of the Saint Catherine's Dock Company, to work all the cranes in those docks, by vacuum engines; this was to be effected by having a steam engine, and air pump, placed in some convenient part of the docks, to produce the vacuum, which was to be communicated to small engines at the cranes by a range of pipe, and thus cause them to work by atmospheric pressure, in the some way as the atmospheric steam engines. This

proposal was declined, it has been said, in consequence of those gentlemen having doubted if the vacuum could be made sufficiently perfect to act at such distances from its source. If a plenum instead of a vacuum had been used, and the pipes thereby charged with air at a density of three or four atmospheres, then, unquestionably, the power might have been sent not only round those docks, but throughout every street in London, if required; and the air for this purpose need not have been raised by the pumps to a density higher than that at which it was to be used, and therefore it would not have required to be drawn down to a working pressure, like that in the locomotive engines, where it is raised to a density of 30 or 40 atmospheres for the sake of portability; and if it had been required to raise one ton only by an engine made to raise ten tons worked with air at the full pressure, it would only have been necessary so to regulate the supply of the fluid, as that a tenth part of the usual quantity should pass through the service pipe, whereby the remaining nine-tenths of the power would have been saved.

A method of supplying manufacturing towns with mechanical power.

Suppose it were contemplated to supply the manufacturers and artizans of Birmingham with cheap power by means of compressed air, just as they are now supplied with cheap light by means of gas; a number of large steam engines erected in the neigh-

bourhood of the nearest coal mines, where the power might be generated from the waste coals, would effect this purpose; and the compressed air might be sent by pipes to reservoirs in different parts of the town, and thence distributed in smaller pipes to work engines of every degree of power, from that of one man to that of fifty horses, if required; and the artizan would have no fire to light or steam to get up, before he began work; turning a cock is all that would be required to start the engine.

The same pipes which supplied power to the manufacturer, would also supply wind for blast furnaces; and even if the waste coals were insufficient to furnish the quantity of power required, it would be cheaper to generate the power at the mines, and send it to Birmingham by means of pipes, than to send the coals to Birmingham and generating the power there; and it would relieve the town of some part of the smoke, and supply fresh air in lieu of it: this may be thought of little consequence at Birmingham, where they have so many other causes of smoke, but it may be of some importance at other places; for instance, at Manchester.

II. The quantity of power that a single pipe would convey appears almost incredible, until reduced to a demonstration: suppose the air were compressed to the density of four atmospheres, (that is, three atmospheres, or 45 pounds on the inch above atmospheric pressure); and suppose the air under that pressure travelled a thousand feet per second, (which

is considerably less than the speed of a single atmosphere when passing into a vacuum,) it would then travel upwards of ten miles in a minute; and a pipe of twelve inches in diameter would be sufficient to convey 1780 cubic feet per second, and consequently 33696000 cubic feet every twelve hours, as under: $1780 \times 60 \times 60 \times 12 = 33696000$ cubic feet; a quantity which, at the density of four atmospheres before mentioned, would be sufficient to work upwards of eleven hundred engines of ten-horse power each. A ten-horse power engine would require between 30 and 40, say 40 feet per minute, or 28800 cubic feet in twelve hours; as $40 \times 60 \times 12 = 28800$: then by dividing 33696000 by 28800, we find this quantity sufficient for 1170 engines of ten-horse power each. And if 25 per Cent. is allowed for the loss of power occasioned by this transfer, it would take 74 engines, of 200 horse power each, to generate the above quantity of power.

It must be almost unnecessary to add that the air should be used expansively, by cutting off the supply at about one third, or one half the stroke, otherwise the waste of power would be considerable.

Mention has been made of the inhabitants of Surrey being supplied with gas manufactured in Kent. London might be supplied in the same manner, with gas manufactured from the waste coal of the mines at Durham;—the distance is of little comparative importance—for, supposing the gas to travel at 1000 feet, or 12000 inches per second, it

would reach London in less than twenty minutes; and a pipe of only three inches in area would be equal to the delivery of one million eight hundred thousand cubic feet in every twenty-four hours, as $12000 \times 3 \times 60 \times 60 \times 24 = 3110400000$ inches, or 1800000 cubic feet; from which not only the gas-holders in London, but also all those in the towns on the road, might be supplied at less than half its present cost: and the citizens of London, as well as the fishes in the Thames, would no longer be poisoned by filth from the gas manufactories.

Iron pipe of three inches area, costs one shilling per foot, or £66000 for 250 miles; so that, provided two ranges of such pipe were laid down to prevent disappointment in the delivery, the outlay would be only £132000: surely, in the present want of employment for capital, this would furnish a profitable investment.

ON PROJECTILE FORCE.

Sometime since Mr. Parkins was trying to obtain a projectile force from steam, that, for all practical purposes, should equal gunpowder. If the method of compressing air, described in the appendix *A*, had then been known, Mr. Parkins might have employed his steam power in compressing atmospheric air to high densities, instead of causing the steam to act directly on the projectile: and there cannot be

a doubt that his object would then have been obtained.

The force of gunpowder is known to be obtained by its generating, when ignited, a permanent elastic fluid, which, at the common temperature, occupies about 244 times the space previously filled by the gunpowder; and if that were the limit of its expansion, it would then be equal to air when under a mechanical pressure of 244 atmospheres: but at the instant of ignition the gunpowder gives out a degree of heat, which causes a much greater momentary expansion of the fluid, and that momentary expansion is estimated as being from two to four times its permanent bulk: such additional expansion depending on the greater or less quantity of gunpowder ignited at a time. When a large quantity is ignited, the heat evolved is supposed to be equal to that of red hot iron, and the fluid is estimated as being expanded to a thousand times the bulk of the gunpowder fired; consequently, the force produced is estimated as equal to air under a mechanical pressure of a thousand atmospheres: but as the force of gunpowder varies in proportion to the quantity used, while that of atmospheric air, under any given pressure, remains the same, it is proposed for the purpose of shewing the comparative expense of projectile force obtained from gunpowder, and that which may be obtained from air when subjected to mechanical pressure, to estimate the average force of gunpowder as equal to air when under a pressure of six hundred atmospheres: and the calcula-

tions founded thereon will furnish data from which the comparative expense may be found, whether the gunpowder is considered as having a greater or less expansive force.

The elastic force of a cubic inch of air, under a pressure of 600 atmospheres, is equal to 4420 pounds weight lifted one foot high, and taking the specific gravity of gunpowder at 780, a pound weight will contain 36 cubic inches; the elastic force of a pound weight of gunpowder will therefore be equal to $4420 \times 36 = 159120$ pounds weight lifted one foot high.* This appears an amazing power when considered as the product of an article, that may be wrapped in a piece of paper and carried in the pocket: but it will appear less amazing when it is considered that a pound weight of pit coal, which costs less than a farthing in London, and not one third part of a farthing in many parts of the kingdom, will, when used in generating steam, produce as much power as *two pounds* weight of gunpowder, which cost not less than three shillings.

* Those persons who are familiar with the force of gunpowder, when used in blasting rocks, will be inclined to think this estimate below the truth. It may therefore be as well to add, that a lift of one eighth of an inch high is sufficient to overcome the adhesion of rocks, and as a pound of gunpowder will lift 159,120 pounds one foot high, it is equal to a lift of 96 times that weight one eighth of an inch high, as under:

$$159120 \times 96 = 15275520.$$

It is not necessary for the purpose of furnishing a quantity of projectile force equal to what is usually expended by an army, to employ engines of great power: for one of the small engines, manufactured by Braithwaite, will generate daily a quantity of power, equal in force to half a ton weight of gunpowder. Such engines might easily be carried with an army, and they may, without any impropriety, be called portable, for they occupy little more space than a portable water closet; an hundred men, out of a regiment or ship's company, would compress as much air per day as would be equal in force to a ton weight of gunpowder. In fact, so little is the comparative quantity of power used for projectile force, that one of the large engines at the mines in Cornwall, probably produced more power during the late war, than was expended in projectile force by all the fleets and armies of Europe together. This will not appear extraordinary, when it is considered that one of the largest of those engines will generate, daily, a quantity of power equal to *thirty tons* weight of gunpowder.

Although air may require to be compressed to a density of six hundred atmospheres before any quantity in bulk would be equal to the same quantity of gunpowder; yet air, under a pressure of 100 or 120 atmospheres has more than twice the speed of the projectile usually thrown; so that if air, at that density, were used, the power required to give the same range as gunpowder, would be obtained by supplying a larger quantity of the fluid.

In the defence of fortified towns, this method would have some advantages over gunpowder, beside its greater economy. All danger from the blowing up of magazines would cease, and one or more steam engines, placed in bomb-proof works or covered ways, would supply all the power required; which might be sent round the ramparts by pipes. The quantity which could be thus conveyed in a range of pipe, made of the size of musket barrels, would be as under:

Suppose the air, at this density, to travel 2000 feet or 24000 inches per second, and the pipe to have an area of half an inch, then it would deliver 24000 cubic inches per second, or 518400000 per day of 12 hours; as $24000 \times ,5 \times 60 \times 60 \times 12 =$ 518400000 inches, or 300000 cubit feet.

A cubic inch of air under a pressure of 120 atmospheres, has an elastic force equal to 630 pounds weight lifted one foot high—a cubic foot, at that density, will therefore be equal to a lift of 1088640 one foot high, as $630 \times 1728 = 1088640$. Three hundred thousand cubic feet will therefore be equal to the lift of 1088640×300000, or 326592000000 pounds one foot high: and as the lift of a pound weight of gunpowder is 159120 pounds weight, one foot high, the quantity of projectile force contained in 300000 cubic feet of air at a density of 120 atmospheres, will be

$$\frac{326592000000}{159120} = 2052488 \text{ pounds,}$$

or 916 tons, 5 cwt. 3 qrs. 4 lbs. of gunpowder.

Losing sight, for a moment, of this immense quantity, it cannot be doubted that a much larger amount of projectile force might, in this way, be made to carry destruction amongst the assailants of a fortified town to a much greater extent than has ever been done by gunpowder.

It may possibly appear pedantic to give the calculations so much in detail, but many of the results are so extraordinary that they would otherwise be scarcely conceivable.

It will be evident that all the advantages above enumerated would apply equally to the Navy, with this addition, that they could carry an immense quantity of such projectile force, ready prepared in reservoirs, placed in the hold; which would serve as ballast and the air would retain its elasticity for years.

It is, perhaps, too much to expect that military engineers, advanced in life, will be convinced that compressed air can be brought into use as a projectile force, to the exclusion of gunpowder. But the civil engineer, who has no preconceived notions to combat, he who can make the steam engine "pick up a pin, or tear up a tree by the roots;" he who has made that machine coin money in London, manufacture ships' blocks at Portsmouth, raise metal from mines 600 fathoms deep in Cornwall, and spin thread and weave cloth at Manchester, will find little difficulty in making atmospheric air, when so compressed, perform the objects contemplated.

CONCLUSION.

Many of the most useful discoveries have been the effect of accident, or rather of what is usually called accident, from their having been the result of a combination of circumstances totally unforeseen, and consequently quite unexpected: probably amongst such accidents this method of propelling locomotive machines, and obtaining projectile force, will be classed when the following circumstances are considered.

On an evening in the year 1827, the patentee was in company with some gentlemen in the Borough, when the subject of conversation was Mr. Gurney's locomotive machine. On his road home the matter occupied his mind, and it occured to him that atmospheric air might be compressed into reservoirs by a steam engine, in the same manner as portable gas, and as the steam power used in the compression of the fluid, must come out on its being suffered to escape, a sufficient quantity of air, when so compressed might, probably, be carried by a locomotive machine to propel it a mile or two. Having been used, from his boyhood, to amuse himself by making mental calculations, he, without contemplating any beneficial results, began by assuming that a locomotive machine might carry twenty reservoirs, each containing four cubic feet of compressed air; then taking the density considerably higher than that of portable gas, and assuming that a four-horse coach required the same quantity of power to propel it ten miles

within an hour as would be produced by a four-horse steam engine in the same time; it came out, to his no little surprise, that the quantity of power which those reservoirs would contain would be sufficient to propel such machine upwards of seventeen miles. Suspecting some error had creeped into his calculations, he tried them again and again, and when he got home he repeated them with a pen; but the result was still the same: he afterwards found his data was considerably erroneous, but it happened that the errors were all on the safe side; he having taken the elastic force of the condensed air too low, and the power required to propel a four-horse coach too high: he then proceeded to find the cost of propelling such a machine from London to Liverpool, by the power of steam so transferred; and, after making some allowance for loss, it came to 18*s*; this calculation also, it afterwards appeared, was too high, being caused by a repetition of his former error—that of taking the horse power when travelling at a speed of ten miles per hour, as equal to a lift of 44000 instead of 22000 pounds one foot high. These calculations, together with some estimates made thereon, were afterwards shown to a number of merchants, bankers, and others; and a member of parliament sent them to one of the most eminent mathematicians in England, from whom they were returned with the following calculation and observation: He commenced the calculations by taking the draft of a horse, when travelling at a speed of ten miles per hour, as equal to a continuing lift of twenty-five pounds, which he multiplied by four,

for the number of horses used in drawing one of the coaches in question, and the product by 52800, the number of feet in ten miles; and then allowing 4720000 for contingencies, he states the result in the following manner:

$$\overline{25 \times 4 \times 52800} + 4720000 = 10000000.$$

He then adds, "Supposing the plan of using compressed air is adopted, the expense of condensation is almost nothing: ten millions is sufficient for ten miles, or one million per mile, and some of our large engines, in Cornwall, perform twenty millions with one quintal of coals." Sanctioned by such authority the patentee proceeded with his plan, and the result is the preceding statement.

In the preceding pages much has been omitted for the sake of brevity, and not a little, lest from its apparent extravangance some readers should think it intended as a tax on their credulity; for instance, where mention is made of supplying the whole line of road from Manchester to London by pipes branching from the coal mines, it might have been added, that two engines, of 150 horse power each, working 12 hours per day, would supply sufficient power to keep 40 machines constantly running between those places during the whole 24 hours. That those engines would cost less than five pounds per day. So that, in the emphatic language of the eminent person before alluded to, the power requisite to convey passengers and goods, to and from Manchester to London, would cost "almost nothing:" and if coke,

on Mr. Surry's patent principle, were made from the same coals that generated the power; the coke could be brought to London by locomotive machines at less than five shillings per ton, and sell for more than would pay for the coals and conveyance; and then the power would cost absolutely "*nothing*."

It might also have been added, that as the quantity of power which could be thus obtained at the coal mines is unlimited: the same range of pipe which supplied the road from Manchester to London would supply London also; for, supposing the fluid at a density of 30 atmospheres, to travel only 1000 feet or 12,000 inches per second, then a pipe of only seven inches in area would, every 12 hours, supply sufficient to keep upwards of 2000 machines continually running, night and day, as $\frac{12000 \times 7 \times 60 \times 60 \times 12}{1728} = 21000$ cubic feet —say 2000 machines 1050 cubic feet each.

Again, it might have been added, that as every object contemplated to be gained by the rail roads would be obtained by a range of pipes on this principle, which would cost less than one fiftieth the expense of a rail road, it may probably render any further extension of that otherwise very desireable plan unnecessary: and perhaps, it may not be too much to anticipate, that, in a comparatively short period of time, we may see every principal, direct, and cross road in the kingdom, supplied with power in the same way (to repeat a former simile) that

every street and lane in London is now supplied with light.

In conclusion, the patentee has only to add, that as his object is to see the plans developed in these pages brought into early and general use, particularly that which relates to locomotive machines on turnpike roads; licences will be granted, on very moderate terms, and should any or all of those gentlemen who have constructed locomotive steam carriages prefer this method to their own, licences for the term of the patent will be granted to them, gratuituously, to run a machine 50 miles a day on any road they may select; and also a refusal of the further traffic, on the same road, at one third less than the charge to other persons, provided application is made on or before the first of June next, by letter, post-paid, to the patentee, Brixton, Surrey.

APPENDIX *A*.

The pumps at present used for condensing elastic fluids have been constructed so as to compress 20, 30, or 40 volumes into the space of one in each pump, at each stroke of the piston; by which means their power is necessarily of a very limited nature; and while this mode of construction is employed, it is scarcely possible to condense such fluid to more than 50 or 60 atmospheres:—and even these densities cannot be attained without a loss of more than two thirds of the power employed in the condensation. The improved pumps, it will be seen, are constructed and worked on an entirely new principle, and by these atmospheric air may be made the vehicle of mechanical power to an almost unlimited extent; the pumps being made to act in a series, and each succeeding pump increasing the density given to the fluid by that which preceded it. To each pump of the series, except the last, there must be attached a small reservoir, for the purpose of receiving the air when compressed, and of furnishing a supply to the next pump in the series. In the aperture which leads from each pump to its reservoir, there must be a valve, to prevent the compressed air from returning into the cylinder of its pump on the re-action of the piston; but no valve will be requisite in the aperture which leads from the reservoir to the succeeding pump; because the air, with all its previously acquired power, is to act on the piston, and aid in depressing it when making the stroke to increase the density of the fluid. There must also be an aperture and valve in the piston of each pump, to permit the air above to pass through into the vacuum produced below, when the piston is ascending, and prevent its return when the piston is descending. If the pumps are made to lift, then, the supply will be from below, and the action of the valves will be reversed; in some respects this method

will be found the best; as, in lifting, there will be no danger of bending the piston rods, whatever may be their length or diameter. The pumps might be made to act both ways like the common steam engine, but there does not appear any material advantages to be derived from that mode of construction. The last pump in the series will force the compressed air into the large reservoirs, to be stored for use, And as there will be a considerable escapement of caloric, during the process of compression, it will be as well to surround the pumps with water.

To show the actions of the pumps on this principle, suppose the air, or other fluid, was required to be raised to any given density, by a ratio of three; that is, by compressing three volumes of air into one in each pump of a series; then the second pump in the series must have only one third, the capacity of the first: the third only one third the capacity of the second; and so of the rest, if more than three. In this manner three pumps only, will raise the density from atmospheric pressure to that of twenty-seven atmospheres, as thus, $3 \times 3 \times 3 = 27$; one additional pump would raise it in the same way from 27 to 81 atmospheres. If four be the ratio, then four pumps will raise the density from atmospheric pressure to 256 atmospheres; thus. $4^4 = 256$, and a fifth pump will raise the density from 256 to 1024 atmospheres; being a density greater than gunpowder. By thus reducing the capacity of the pumps in succession, by the same ratio as the density of the fluid is increased, the total pressure on the piston of each pump will be the same, whatever the density of the fluid; for instance, the total pressure on the piston of the last pump, in the preceding series, which raised the density from 256 to 1024 atmospheres, is no greater than the total pressure on the piston of the first pump, which raised it from one to four atmospheres.

The following detail of the process will, probably, show the advantages derived from this method more satisfactorily:

Let each of a series of three pumps be twenty-four inches in length, and be worked on a three-throw crank. Let the area of the first pump be 90 squares inches, then the area of the second must be 30 square inches, and that of the third 10 square

inches. Then the first pump being 24 inches in length, and its area being 90 square inches, its capacity will be $24 \times 90 = 2160$ cubic inches. It will, therefore, at each stroke of the piston, receive into its cylinder 2160 cubic inches of atmospheric air, at its natural pressure of about fifteen pounds in the square inch, and by compressing three volumes into the space previously occupied by one, the bulk will be reduced from 2160 to 720 cubic inches, and the density increased from atmospheric pressure to that of three atmospheres. The second pump being of the same length as the first, but having an area of only 30 square inches, its capacity will be $24 \times 30 = 720$ cubic inches. That pump will therefore receive 720 cubic inches of air, previously compressed to the density of three atmospheres, and by again compressing three volumes into one, the bulk will be further reduced from 720 to 240 cubic inches, and the density increased from three to nine atmospheres. The third pump of the series being also 24 inches in length, but having an area of only 10 inches, its capacity will be $24 \times 10 = 240$ cubic inches: it will therefore receive the 240 cubic inches of air previously compressed to nine atmospheres, and by compressing three volumes into one, the bulk will be further reduced from 240 to 80 cubic inches, and the density increased from nine to twenty-seven atmospheres.

The following table will exhibit at one view, the arrangement of the three pumps as above detailed, shewing, at the same time, the increasing density of the fluid as it passes through them in succession.

	Number of atmospheres of compression or density, to which the air is raised in each pump.		Pressure per inch on the air when at the maximum of the stroke in each pump.		Pressure per inch on the air at the commencement of the stroke of the piston.		Mechanical pressure per inch, added to the previous pressure by each pump.		Area of the pistons and cylinders.		Total pressure on the piston of each pump when at the maximum.
First pump	3	=	45	—	15	=	30	×	90	=	2700
Second ditto	9	=	135	—	45	=	90	×	30	=	2700
Third ditto	27	=	405	—	135	=	270	×	10	=	2700

This table shews, as before mentioned, that by this arrangement the pressure on the pistons of the pumps is equalized.

Again, suppose it was required to compress a quantity of air to the density of 64 atmospheres by a ratio of 2; that is, by compressing only two volumes into one in each pump, then it would require six pumps to compress it to a density of sixty-four atmospheres, as $2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$.

The capacity of each succeeding pump, in the series, must then be diminished by a ratio of only two, the density being increased by such ratio.

Let each pump be 24 inches in length, and the area of the first 160 square inches; the area of the second will then be 80 inches, the third 40, the fourth 20, the fifth 10, the sixth and last 5 inches. The following table will exhibit, at one view, the result of such arrangement:

	Number of atmospheres of compression or density to which the air is raised in each pump.	Pressure per inch on the fluid, when at the maximum of the stroke of the piston.	Pressure per inch on the fluid at the commencement of the stroke of the piston.	Mechanical pressure per inch added to the previous pressure by each pump.	Area of the pistons and cylinders.	Total pressure on the piston of each pump when at the maximum.
First pump	2 =	30 —	15 =	15 +	160 =	2400
Second ditto	4 =	60 —	30 =	30 +	80 =	2400
Third ditto	8 =	120 —	60 =	60 ×	40 =	2400
Fourth ditto	16 =	240 —	120 =	120 +	20 =	2400
Fifth ditto	32 =	420 —	240 =	240 +	10 =	2400
Sixth ditto	64 =	960 —	480 =	480 +	5 =	2400

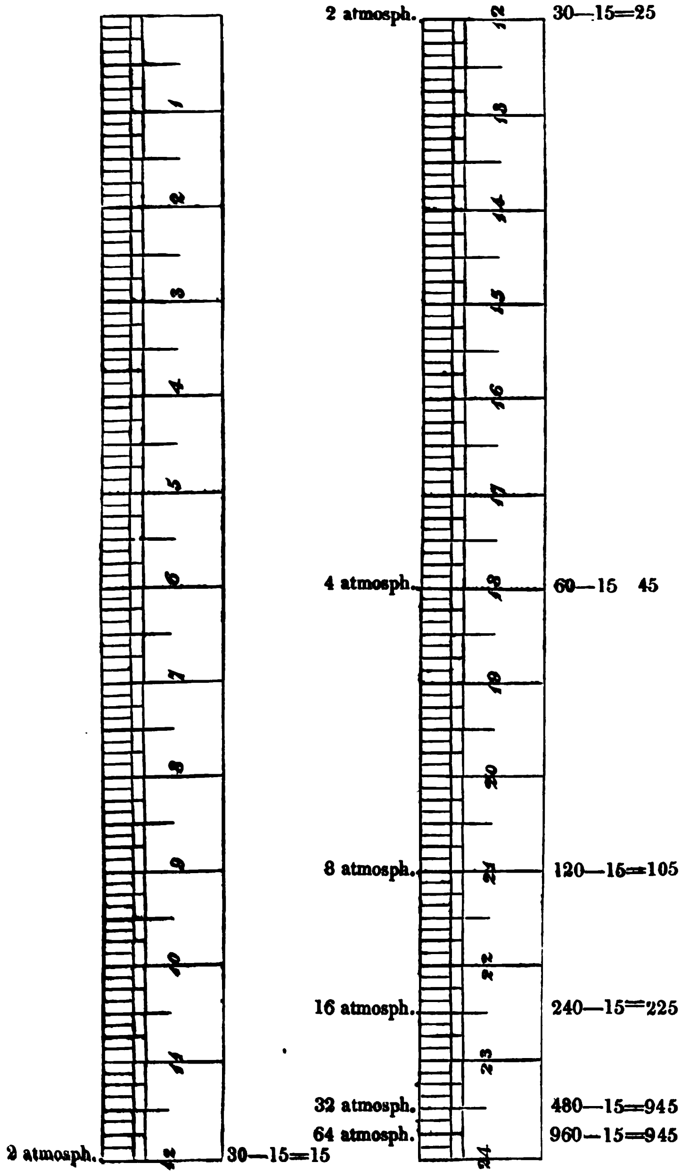
The difference between this method of compressing elastic fluids to high densities and that hitherto practised will be evident, by supposing the same quantity of air was to be compressed to the same density of 64 atmospheres in a single pump of the same length and area as the first of that series; then, instead of *six times*, it would require *sixty-three* times the power to depress the piston at the end of the stroke, that would be required by the same pump when forming one of a series of six on the improved plan; this will appear on contrasting the two methods of condensation.

	Number of atmospheres,	Pressure per inch.	Atmospheric pressure.	Mechanical pressure.	Area of pistons and cylinders.	Total pressure on the pistons, &c.
The first pump when one of a series of six	2 =	30 —	15 =	15 ×	160 =	2400
The same pump when acting singly	64 =	960 —	15 =	945 ×	16 =	151200

This inconvenience, indeed, would be partially removed by using several pumps with small areas, making altogether the same area of 160 square inches. Suppose six pumps were used, being the same number as in the preceding series; the areas of each of them would then be $160 \div 6 = 26\frac{2}{3}$ square inches. The power required to depress the piston of each pump at the end of each stroke, would be $10\frac{1}{2}$ times that required by the improved pumps acting in a series; that is, each piston would require a pressure of 25200 pounds instead of 2400 pounds. Those six pumps might be worked on a six-throw crank, and the result would be as follows:

	Number of atmospheres.	Pressure per inch.	Atmospheric pressure.	Mechanical pressure.	Area of cylinder.	Total pressure on the pistons.
First pump	64 =	960 —	15 =	945 ×	$26\frac{2}{3}$ =	25200
Second ditto	64 =	960 —	15 =	945 ×	$26\frac{2}{3}$ =	25200
Third ditto	64 =	960 —	15 =	945 ×	$26\frac{2}{2}$ =	25200
Fourth ditto	64 =	960 —	15 =	945 ×	$26\frac{2}{3}$ =	25200
Fifth ditto	64 =	960 —	15 =	945 ×	$26\frac{2}{3}$ =	25200
Sixth ditto	64 =	960 —	15 =	945 ×	$26\frac{2}{3}$ =	25200

The great difference in the quantity of power required to compress the same quantity of air by one set of pumps, and that which is required by the other, will probably appear more evident on inspecting the following diagram of a pump, 24 inches in length:


2 atmosph.
30—15=25
4 atmosph.
60—15 45
8 atmosph.
120—15=105
16 atmosph.
240—15=225
32 atmosph.
480—15=945
64 atmosph.
960—15=945
2 atmosph.
30—15=15
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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19
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23
24

On referring to this diagram it is seen, that when elastic fluids are subjected to mechanical pressure to increase their density, the piston of the condensing pump must always pass half way down the cylinder before it acquires a density of two atmospheres; and when the pressure is continued in the same pump it must pass through half the remaining half, (that is, to the end of the eighteenth inch in that diagram) before it acquires a pressure of four atmospheres; and again through half the remaining space, (that is to the end of the twenty-first inch) before it acquires a density of eight atmospheres.

Proceeding in this way the piston must be depressed within three eights of an inch of the bottom of the cylinder before the air acquires a density of sixty-four atmospheres, so that the piston passes through twenty-three inches and five-eighths out of the twenty-four inches, before it reaches the required pressure; and, consequently, it has only a space of three-eighths of an inch to pass through, at the maximum pressure in forcing the condensed fluid into the reservoirs : but as the piston cannot be permitted to strike the bottom of the cylinder, a very considerable part of the air compressed within that space, and which ought to be forced into the reservoirs, will remain behind, and return to atmospheric pressure on the ascent of the piston; whereby all the power expended in compressing that part is totally lost; and this loss is sustained in addition to a maximum power of 25200 pounds being required for each pump, instead of only 2400 pounds, when the air is compressed by the improved pumps, in which the piston of each pump reaches its maximum pressure in the first twelve inches, and has therefore a space of twelve inches, within which to exert its maximum pressure instead, of three-eights of an inch. Again, suppose it were required to increase the density to 128 atmospheres on the old principle, it would, if practicable, require the piston of each of the pumps to approach within three sixteenths of an inch of the bottom of the cylinder with a pressure of 50,400; whereas by the addition of one pump to the series of six, with half the area of the last one, the fluid would be doubled in density with only one-sixth more power.

The reservoirs made for containing the air when compressed, are constructed on the same principle as those used for portable

gas, which are too well known to need description. The cylindrical ones, made of malleable iron, are so perfectly adapted for this purpose as scarcely to admit of improvement, excepting that, if constructed of the best malleable steel, they would sustain nearly double the pressure without increasing their weight. The most convenient dimensions appear to be from four to five feet in length, and from nine to twelve inches in diameter. But when the reservoirs are required to contain air at very high densities, for supplying a projectile force, a diameter from three to six inches will probably be found the most advantageous and convenient for strength and weight.

APPENDIX *B.*

A TABLE,

SHEWING THE LIFT OF A CUBIC INCH OF AIR AT THE FOLLOWING DENSITIES.

Number of atmospheres of compression.		Lift in pounds weight one foot high of the propelling and expanding force of a cubic inch of compressed air, when discharged from a reservoir into the expanding cylinder of a machine.		Lift in pounds weight one foot high of the propelling force when issuing from the reservoir.		Lift in pounds weight one foot high of the expansive force, after deducting the propelling force from the total lift.
4	=	7,50	—	3,75	=	3,75
8	=	22,50	—	8,75	=	13,75
12	=	40,00	—	13,75	=	26,25
16	=	60,00	—	18,75	=	41,25
20	=	80,62	—	23,75	=	56,87
24	=	102,50	—	28,75	=	73,75
28	=	125,62	—	33,75	=	91,87
32	=	150,00	—	38,75	=	111,25
36	=	174,06	—	43,75	=	130,31
40	=	198,74	—	48,75	=	149,99
44	=	224,06	—	53,75	=	170,31
48	=	250,00	—	58,75	=	191,25
52	=	276,56	—	63,75	=	212,81
56	=	303,76	—	68,75	=	231,05
60	=	331,56	—	73,75	=	257,81
64	=	360,00	—	78,75	=	281,25

In the preceding table there are three columns exclusive of that in which the degrees of compression are stated numerically. In the first of those columns is given the entire lift of a cubic inch of air on its isuing from the reservoir; the second gives the lift of the propelling power; and the third the lift of each cubic inch by its expansive power: thus the gross lift of an

inch of air, at a density of 64 atmospheres, is stated to be equal to the power required to lift 360 pounds one foot high; which lift of 360 pounds is composed of an expansive force equal to 281,75 pounds lifted one foot high, and a propellling force equal to 78,75 pounds lifted one foot high..

In the preceding calculations of the amount of power contained in a given quantity of compressed air, the expansive force alone is estimated. The reason for this will perhaps be under stood, when it is explained, that what is called the propelling force is produced by no inherent power in the portion of air suffered to escape, but by that portion of air being driven out by the expansion of every particle of air remaining in the reservoir whilst filling up the space which the escaping air had previously occupied; and accordingly it is found, that not only is the quantity of power reduced to the extent of all the air which has been suffered to escape, but that the density of the remainder is also reduced by its filling a larger space than previously; and this reduction in density or expansive force, as it is called, is found to correspond exactly with the amount of propelling power which it has exerted in filling up the additional space.

The foregoing table may possibly require some further explanation, as from that table it appears, as the fact is, that a cubic *inch* of air, at a density 64 atmospheres, contains 16 times as much power as one at eight atmospheres.

This may probably lead to the misconception that an *atmosphere* also at 64 contains 16 times as much power as one at 8; whereas, in truth, an atmosphere at 64 contains only twice as much power as one at a density of eight. This will appear by the following calculation: Suppose a reservoir made to contain a cubic foot or 1728 cubic inches, were charged with 64 atmospheres, it would then contain 64 times 1728 cubic inches of common air; and as each cubic inch, at that density, would contain 64 inches of common air, an atmosphere of 1728 cubic inches would contain only 27 cubic inches at that density, as $1728 \div 64 = 27$. When the air is reduced to eight atmospheres then a cubic inch, at that density, contains only eight cubic inches of common air; so that an atmosphere of 1728 cubic inches will furnish 216 cubic inches at the latter density.

A cubic inch of air at 64 atmospheres has a gross lift equal

to 360 pounds one foot high : 27 cubic inches, which constitute that atmosphere, will therefore lift 9720 pounds one foot high, as $360 \times 27 = 9720$.

A cubic inch of air at 8 atmospheres has a gross lift equal to 22,5 one foot high; 216 cubic inches, which constitute that atmosphere, will therefore lift 4860 pounds one foot high, as $22,5 \times 216 = 4860$.

So that the gross lift of an atmosphere at 64 being 9720, and the gross lift of an atmosphere at 8 being 4860, the difference between an atmosphere at 64 and one at 8 is only as two to one; although the difference between a cubic inch, at those densities, is as sixteen to one.

APPENDIX *C.*

The portable gas reservoirs made to contain three and a half cubic feet at 30 atmospheres are 12 inches in diameter, consequently 37,71 inches in circumference, and 113,13 in area. Their thickness is one ninth of an inch ; so that the quantity of metal which the fluid would have to tear asunder, in order to burst one of these reservoirs, is $37,71 \div 9 = 4,19$ square inches, or 5,33 circular inches.

An iron wire of one inch in diameter is capable of sustaining a weight of 45000 pounds: one of the portable gas reservoirs, of the dimensions before mentioned, is therefore capable of sustaining a pressure of $45000 \times 5,33 = 239850$ pounds.

Now dividing this total amount of resistance by 113,13, the area of the reservoir, it is found that such reservoirs are capable of sustaining 2120 pounds on the square inch, or rather more than 141 atmospheres, as

$$\frac{239850}{113,13} = 2120 \text{ pounds, or } 141,33 \text{ atmospheres.}$$

APPENDIX *D*.

The expansive force of an inch of air under a pressure of 32 atmospheres, will be found on reference to the table in Appendix *B*. to be equal to 111,25 pounds lifted one foot high. If therefore we multiply this by the number of inches in a cubic foot, and that product by 300, the number of feet, we shall have the amount of power contained in that quantity of air at the given density, thus:

$$111{,}25 \times 1728 \times 300 = 57672000.$$

The power requisite to propel a ton weight one mile on a rail-road, is estimated as equal to a lift of 39600 pounds: twenty tons will therefore require $39600 \times 20 = 792000$.

Dividing the former product by the latter we find that the power contained in 300 cubic feet of air at a density of 32 atmospheres, is equal to the propulsion of 20 tons 72,81 miles on a rail-road: as

$$\frac{57672000}{792000} = 72{,}81 \text{ miles},$$

In the same table we find the expansive force of a cubic inch of air at a density of 64 atmospheres to be 281,25 pounds lifted one foot high. Treating this in the same way, our calculation will stand thus: $281{,}25 \times 1728 \times 300 = 145800000$, then

$$\frac{145800000}{792000} = 184{,}09 \text{ miles}.$$

So that the distance which 300 cubic feet of air at 64 atmospheres would propel 20 tons weight on a railway is 184,09 miles.

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